NASA TECHNICAL NOTE

NASA TN D-2663

c. 1

NASA TN D-2663

EVALUATION OF FIVE BEARING-SEPARATOR MATERIALS AND POLYPHENYL ETHER LUBRICANTS FOR USE IN SPACE POWER GENERATION SYSTEMS

by William R. Loomis

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1965

-2663

EVALUATION OF FIVE BEARING-SEPARATOR MATERIALS AND POLYPHENYL ETHER LUBRICANTS FOR USE IN SPACE POWER GENERATION SYSTEMS

By William R. Loomis

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Office of Technical Services, Department of Commerce,
Washington, D.C. 20230 -- Price $1.00

EVALUATION OF FIVE BEARING-SEPARATOR MATERIALS AND POLYPHENYL ETHER LUBRICANTS FOR USE IN SPACE POWER GENERATION SYSTEMS

by William R. Loomis

Lewis Research Center

SUMMARY

The suitability of five bearing-retainer materials (iron-silicon bronze, S-Inconel, Stellite Star-J, M-2, and M-50) for ultimate use in the mainshaft rolling-element bearings of the SNAP-8 space power generation system was determined in a series of friction and wear experiments. Polyphenyl ether lubricant (type 4P3E) was supplied at 250° F from a drip-feed, once-through system at a rate sufficient to maintain boundary lubricating conditions. The specimen configuration consisted of a hemispherical rider (3/16-in. rad., representing the retainer) sliding at 3600 feet per minute against the flat surface of a rotating disk ($2\frac{1}{2}$-in.-diam. M-50 high-speed tool steel, representing the raceway and the rolling element) ~300° F.

Minimum friction coefficients and the lowest total disk and rider wear were obtained with the iron-silicon bronze specimen, but the other four retainer materials had acceptable friction properties and rider wear volumes in the same order of magnitude as the bronze. There was a buildup of black, amorphous sludge-like material along the edges of the disk wear track and in the used lubricant. This material was analyzed to be approximately half carbonaceous matter and half iron (assumed to be iron oxide), which indicated some localized lubricant breakdown and some wear debris. The bulk effect of these tests on the lubricant was not significant as measured by neutralization number and kinematic viscosity changes.

Accelerated thermal stability and liquid compatibility studies for four- and five-ring polyphenyl ether liquids (4P3E and 5P4E) in contact with mercury were conducted in a simple device (reaction bomb). The conditions simulated those expected in the SNAP-8 operating environment, except for exposure to radiation. Extrapolation of these results indicated that no stability or liquid compatibility problems should be encountered after 10 000 hours at a liquid temperature of 300° F. Infrared spectral analyses were used to verify that no gross lubricant breakdown occurred.

INTRODUCTION

Successful operation of space power generation systems such as SNAP-8 will depend largely on the reliability of the main-shaft rolling-element bearings and their lubrication system for a 10 000-hour unattended service life in a space environment. The lubrication system will be a closed, recirculating system; however, the lubricant, bearings, and gears will be exposed to varying low-pressure levels down to the vapor pressure of the lubricant (ref. 1). Contact of the lubricant with mercury from the heat-rejection loop can also be anticipated. The use of one of the better radiation-resistant, high-temperature fluids such as a mixed-linked four-ring polyphenyl ether has been considered (ref. 2). Fully hardened M-50 tool steel shows promise as the bearing raceway and rolling-element material. The selection of a suitable bearing-separator material remains the prime requisite of such systems.

Problems are anticipated because of the friction and wear characteristics of various combinations of metals in sliding contact with polyphenyl ether under boundary lubricating conditions expected in space power generation systems. Work done by several investigators (refs. 3 and 4) shows evidence of poor lubrication, high friction, and incipient seizure during the testing of mixed-linked five-ring polyphenyl ethers under high loads in a four-ball wear tester (with 52100 steel balls at 167° F). The test fluids darkened and were found to contain large quantities of metal particles and nonmetallic sludge-like material. The stress levels in these tests (300 000 to 600 000 psi), however, are considered much more severe than those expected for rolling contacts in the SNAP-8 application (150 000 psi).

The relatively poor lubricating ability of polyphenyl ether may be partly explained by its lack of reactivity with the metal surface and the atmosphere. More information is needed, however, on the performance of this lubricant with various bearing metals. Earlier investigations (ref. 5) suggested the possible detrimental catalytic action of copper and copper-containing alloys that produced harmful sludges in the lubrication system. Later studies, however, at the Naval Research Laboratory (ref. 6) suggest that bearing-retainer materials should include such pro-oxidant materials as iron-silicon bronze.

The degradation of polyphenyl ethers and the resulting effect of such decomposition products are of vital concern in this application. Too much importance should not be placed on lubricant darkening in the study reported herein because fluid darkening alone cannot be used as a criterion of degradation.

The general objective of this investigation was the comparative evaluation of five materials under conditions generally simulating the operation of space power generation system bearings to determine which was the most suitable bearing-separator material. More specifically, the work performed at the Lewis Research Center included the following:

(1) The friction and wear characteristics were determined for various candidate bearing-separator materials in the form of hemispherically shaped riders sliding on flat disk specimens of M-50 tool steel. An attempt was made to simulate a disk temperature of 300° F under boundary lubricating conditions with deaerated polyphenyl ether lubricant (type 4P3E) at an inlet temperature

of 250° F and an ambient pressure of about 40 millimeters of mercury in a drip-feed, once-through system.

(2) The effects of test specimen material combinations on appearance and other characteristics of the lubricant were investigated.

(3) Thermal stability and compatibility of the lubricant when exposed to liquid mercury were determined.

APPARATUS AND PROCEDURE

Friction and Wear Apparatus

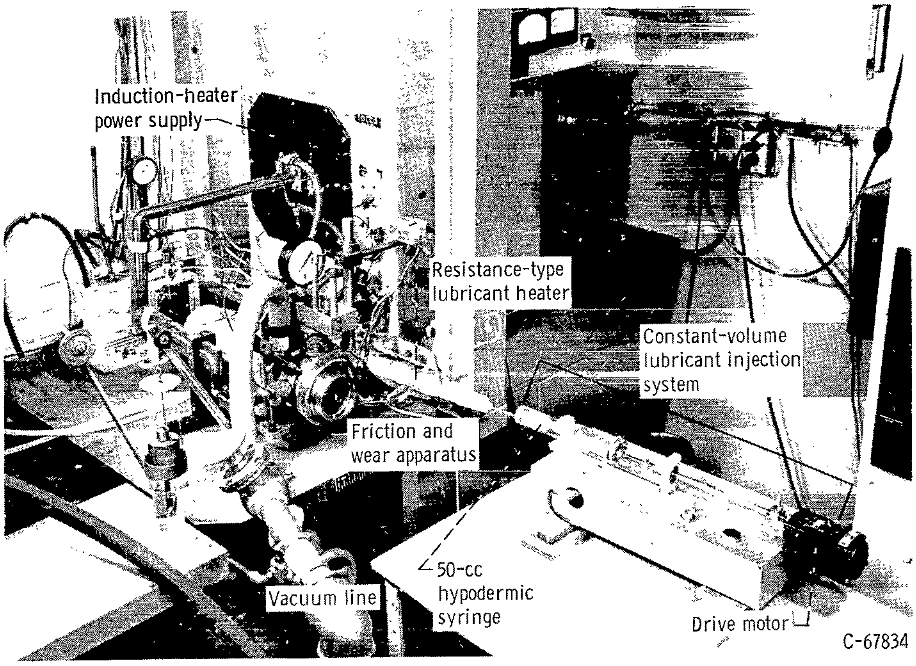
The friction and wear apparatus used in this study is shown in figure 1. Basically, the apparatus consists of a rotating-disk specimen of hardened (Rockwell C-63) M-50 tool steel ($2\frac{1}{2}$-in. diam.) placed in sliding contact with a stationary hemispherically tipped rider (3/16-in.-rad. hemisphere) under a normal load of 1000 grams. The five rider materials under investigation were (1) copper alloy (iron-silicon bronze), (2) nickel alloy (S-Inconel), (3) cobalt alloy (Stellite Star-J), (4) high-speed tool steel (M-2), and (5) high-speed tool steel (M-50).

The rider specimen traverses a 1.81-inch-diameter wear track on the disk with unidirectional sliding at a controlled velocity of 3600 feet per minute. The rider is loaded by dead weights applied to the disk surface through a retaining arm that is gimbal-mounted and sealed with a flexible bellows. Friction torque is measured with a strain gage and continuously recorded.

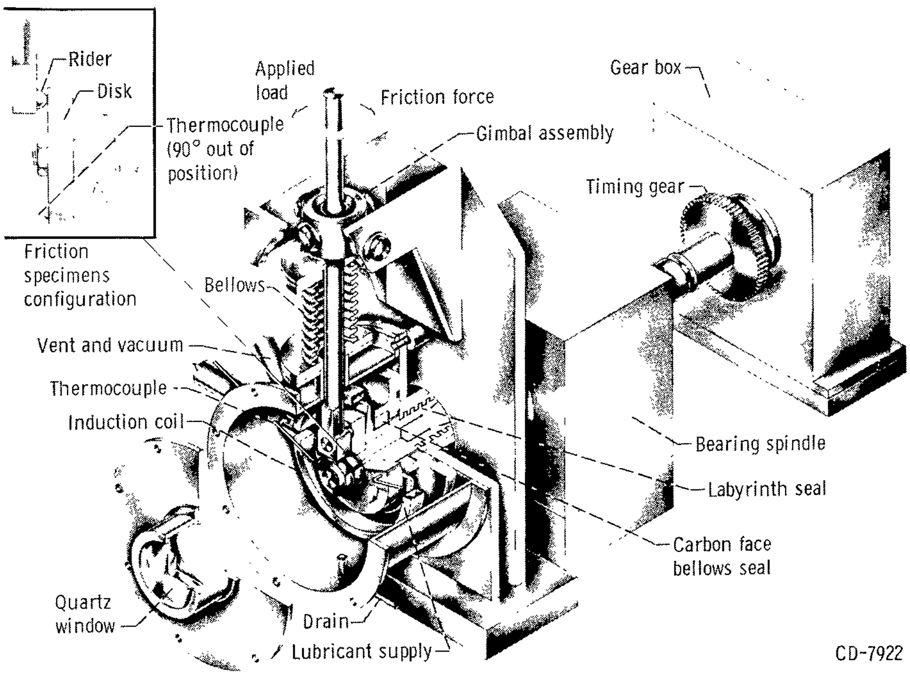
The disk specimen is rotated at 7590 revolutions per minute by a variable-speed drive unit through a gear box and spindle assembly. A magnetic pickup is used to monitor rotative speeds. The test disks are heated with an induction heater around the circumferential surface of the disk. An attempt was made to stabilize the disk temperature at 300° F. Temperature is measured with a Chromel-Alumel thermocouple located 1/16 inch away from the disk wear track in the disk quadrant about 270° downstream from the lubricant inlet nozzle (see Friction Specimen Configuration in fig. 1(b)). The thermocouple is calibrated to permit approximate measurements of the surface temperature of the rotating disk.

The lubricant used throughout this study was an unsubstituted mixed-linked four-ring polyphenyl ether (Dow ET-378). It was injected into the Inconel test chamber at a temperature of 250° F by a mechanically driven glass syringe at a rate of 0.415 cubic centimeter per minute. The temperature of the lubricant was measured just before the lubricant entered the rig. The lubricant was directed at the disk wear track by means of a 1/8-inch stainless-steel tube with a restricted tip. Lubricant temperature was maintained with a resistance-type heater outside the test chamber located between the syringe and the inlet nozzle.

An ambient absolute pressure of 40 millimeters of mercury was maintained in



(a) Overall view showing lubricant injection system.



(b) Details of test apparatus.

Figure 1. - Friction and wear test apparatus.

the test chamber with a 15-cubic-foot-per-minute capacity mechanical vacuum pump during the runs (all of 1-hr duration). (Therefore, there was an appreciable leakage of air through the chamber.) The used and excess lubricant was drained from the bottom of the test chamber after each run.

All disk and rider specimens were finish-ground to a surface finish of 4 to 8 microinches and were cleaned before each test in the following manner:

(1) Rinsed with acetone

(2) Scrubbed with moist levigated alumina and a soft polishing cloth

(3) Thoroughly rinsed with tap water

(4) Rinsed briefly with distilled water

(5) Rinsed with ethyl alcohol

Accelerated Thermal Stability and Compatibility Study Apparatus

The high-temperature, low-pressure liquid compatibility and thermal stability study was made with the reaction bomb shown in figure 2. Separate tests were made with 15 milliliters of two deaerated polyphenyl ether fluids in contact (interface area of 0.37 sq in.) with equal volumes of liquid mercury for

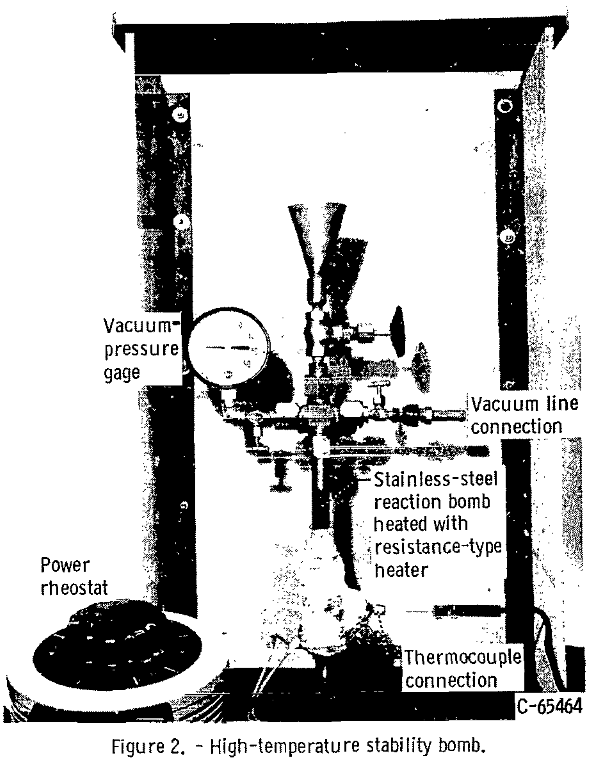


Figure 2. - High-temperature stability bomb.

TABLE I. - PHYSICAL AND MECHANICAL PROPERTIES OF BEARING-RETAINER MATERIALS TO BE USED IN SPACE POWER GENERATION SYSTEMS

Material (and designation)	Primary data source	Condition	Nominal chemical composition, percent	Yield strength (at 70° F), psi	Compressive strength, psi	Rockwell hardness (converted to Rockwell A scale) at -		Density, lb/cu in.	Mean coefficient of thermal expansion (at 300° F), in./in./°F
						Room temperature	300° F		
Iron-silicon bronze (ASTM B98, type A)	Reference 8	Wrought	Silicon, 2.5 to 4; iron, 1 to 2; zinc, 1.5 to 4; manganese, 1; copper, balance	22×10^3 to 30×10^3	15×10^3 to 22×10^3 (at 70° F)	[a]B-62 (A-40)	--------	0.307	-------
S-Inconel (Inconel 705)	Reference 9	As cast	Nickel, 69.5; copper, 0.5; silicon, 5.5; iron, 8; manganese, 0.9; chromium, 15.5; carbon, 0.3	80×10^3 to 100×10^3	----------	[b]300 to 380 Bhn (A-64)	--------	0.292	7.1×10^{-6}
Stellite Star-J	Reference 10	Chill cast	Nickel, 2.5; silicon, 1; iron, 3; manganese, 1; chromium, 32; tungsten, 17; carbon, 2.5; other, 2; cobalt, balance	75×10^3	335×10^3 (at 70° F)	[a]C-61 (A-81)	[a]C-58	0.316	6.7×10^{-6}
M-50 high-speed tool steel (AISI 4-4-1)	Reference 11	Heat treated at 2050° F for 20 minutes, oil quenched, and double tempered at 1000° F for 2 hours	Nickel, 0.1; silicon, 0.4; manganese, 0.3; chromium, 4; carbon, 0.8; vanadium, 1.05; molybdenum, 4.2; iron, balance	338×10^3	358×10^3 (at 400° F)	[a]C-62 to C-64 (A-82)	[a]C-61 to C-63	0.291	5.99×10^{-6}
M-2 high-speed tool steel (AISI 6-5-2)	References 8 and 11	Heat treated at 2250° F for 10 minutes, oil quenched, and double tempered at 1050° F for 2 hours	Nickel, 0.1; silicon, 0.3; manganese, 0.3; chromium, 3.8, tungsten, 6.4; carbon, 0.8; vanadium; 1.8; molybdenum, 4.9; iron, balance	445×10^3	392×10^3 (at 400° F)	[a]C-66 (A-85)	[a]C-64	0.295	6.52×10^{-6}

[a]Experimental data.

[b]At 3000 kg test load in hardness test.

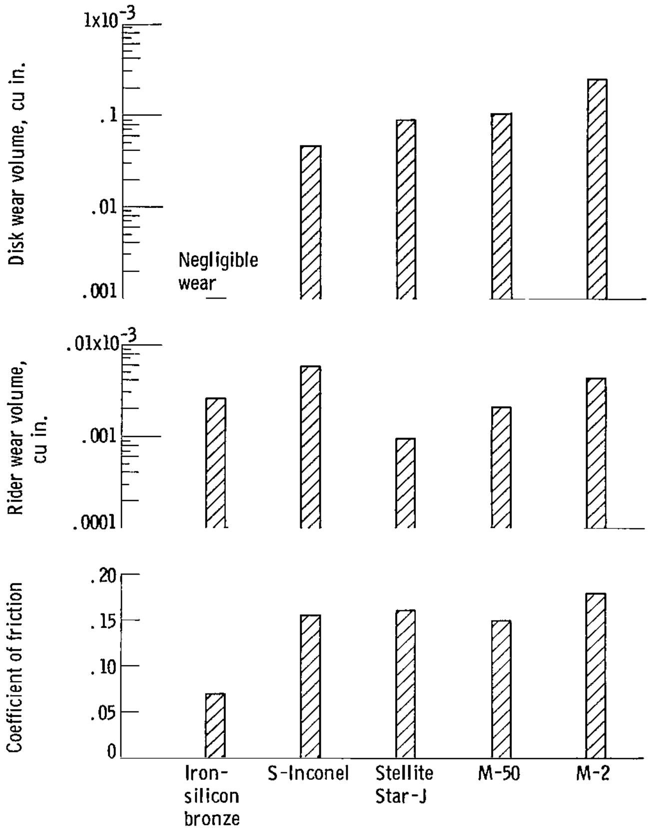


Figure 3. - Coefficient of friction and rider and disk wear for five bearing-retainer materials sliding on M-50 disks at ~300° F. Lubricant, polyphenyl ether; lubricant flow rate at 250° F, 0.415 cubic centimeter per minute; sliding velocity, 3600 feet per minute; load, 1000 grams; duration, 1 hour; ambient pressure, ~40 millimeters of mercury.

extended periods at elevated temperatures. After the bomb was filled, it was evacuated to an absolute pressure of 3 inches of mercury and sealed off. The contents were heated to the desired test temperature and maintained there by means of electrical resistance-type heaters wrapped around the bomb.

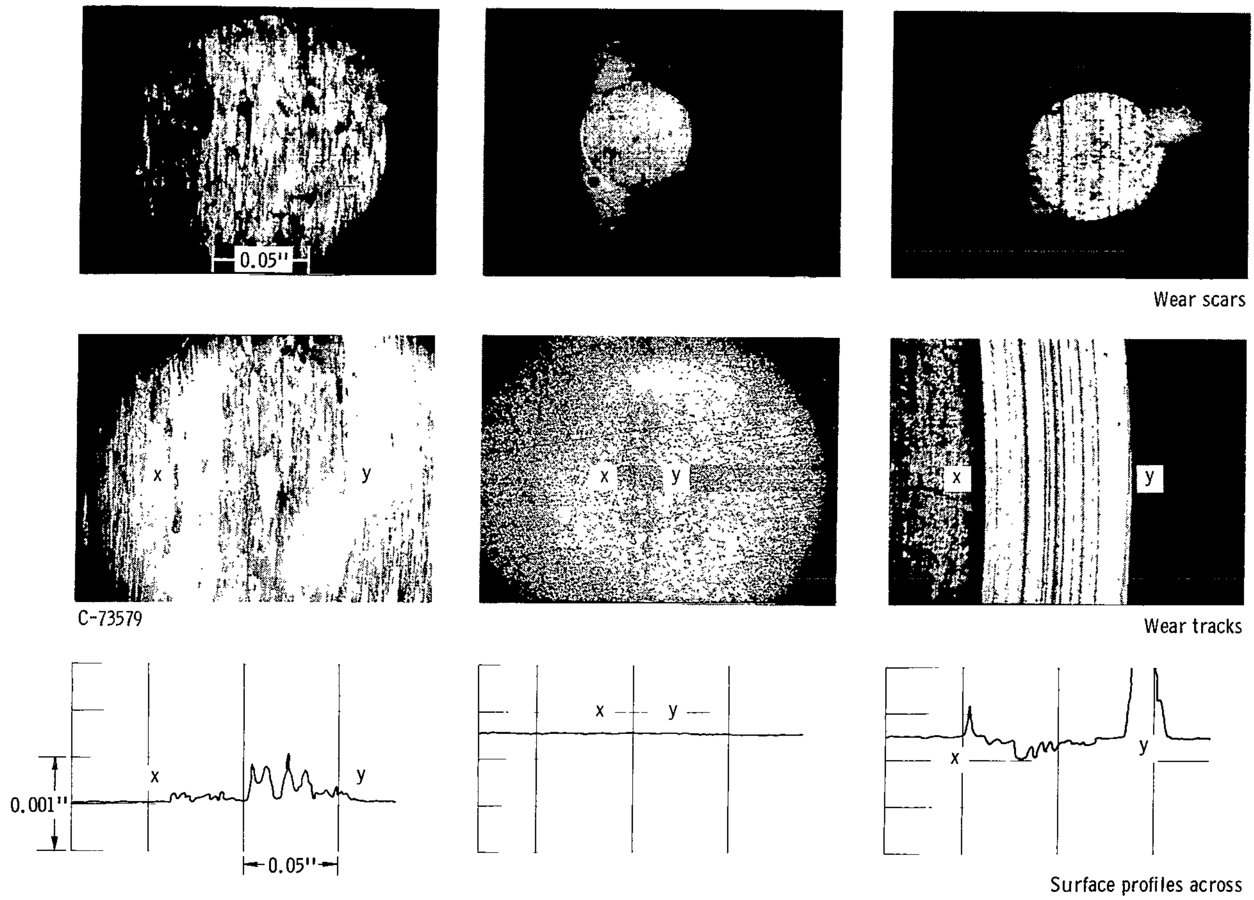
A mixed-linked four-ring polyphenyl ether (4P3E, ET-378) was used in one stability run at a temperature of 365° F for a continuous test lasting 818 hours. The other reported run was with a mixed-linked five-ring polyphenyl ether (5P4E, Monsanto OS-124) at 650° F for 260 hours.

After the completion of each run, the contents of the bomb were removed and the mercury and the lubricant were separated physically (by decanting and centrifuging). Infrared spectroscopy data were obtained for the lubricant portion of the test liquid by means of an infrared spectrophotometer with a 2- to 16-micron wavelength range. The lubricant was diluted with carbon tetrachloride before it was placed in the instrument test cell. The reference cell contained carbon tetrachloride.

Bearing Materials

The selection of the various bearing-retainer materials was based on anticipated requirements for their use in the SNAP-8 space power generation system. These materials have mechanical properties that are equal to or better than those of materials currently used in rolling-contact bearings. An exact, dependable calculation of the strength requirement for retainers is impossible because all the variables cannot be evaluated (ref. 7).

The physical and mechanical properties of the materials used in the friction and wear experiments reported herein are listed in table I. The properties considered most important for this application (ref. 12) are (1) dimensional stability, (2) oxidation and corrosion resistance, (3) friction and wear characteristics in boundary lubricating conditions, (4) hardness, and (5) strengths (compression, shear, and tensile).



(a) Non lubricated iron-silicon bronze rider; run duration, 15 seconds.

(b) Lubricated iron-silicon bronze rider; run duration, 1 hour.

(c) Lubricated S-Inconel rider; run duration, 1 hour.

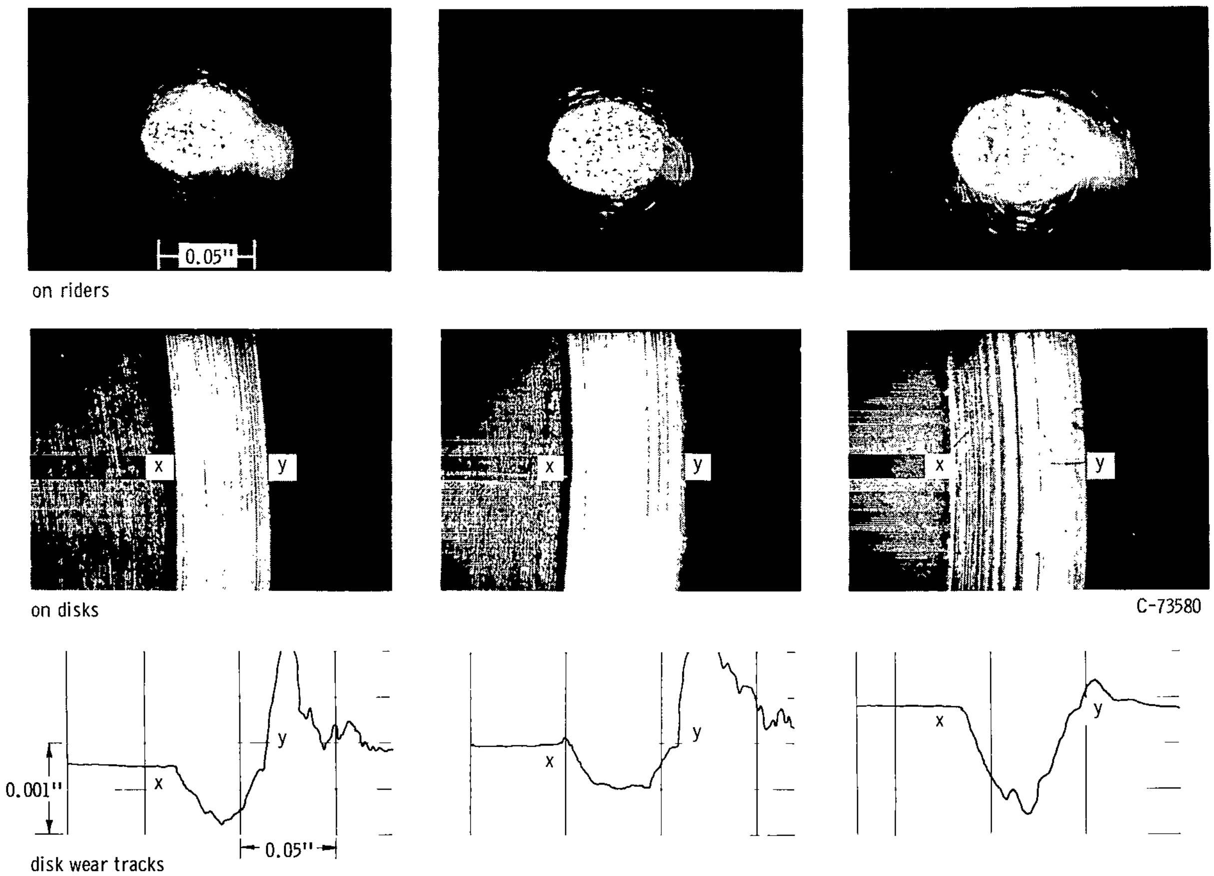
Figure 4; - Wear scars of various riders sliding on M-50 disks at ~300° F. Lubricant, polyphenyl ether; lubricant flow rate at 250° F, mercury. (x and y are reference points.)

Iron-silicon bronze was studied because it is one of the most widely used machined retainer material for rolling-element bearings (ref. 13). It should perform well in an oxygen-deficient atmosphere because the silicon acts as an oxygen getter to form desirable surface films. S-Inconel was chosen because of the previous success of nickel-base alloys as bearing-retainer materials (ref. 13). Stellite Star-J, a cast cobalt-base alloy, was selected because it has strength and film-forming ability. The tool steels (M-2 and M-50) were picked because of their good dimensional stability and hardness.

RESULTS AND DISCUSSION

Friction and Wear Results

The experimental data in figure 3 indicate the typical coefficient of friction and specimen wear results for the five retainer materials. All materials had relatively low rider wear volumes in the same order of magnitude (0.001×10^{-3} to 0.006×10^{-3} cu in.). Coefficients of friction were also all



(d) Lubricated Stellite Star-J rider; run duration, 1 hour.

(e) Lubricated M-50 tool-steel rider; run duration, 1 hour.

(f) Lubricated M-2 tool-steel rider; run duration, 1 hour.

0.415 cubic centimeters per minute; sliding velocity, 3600 feet per minute; load, 1000 grams; ambient pressure, ~40 millimeters of

relatively low. The value for iron-silicon bronze was 0.07, which was less than one-half the values for the other materials (0.15 to 0.18). Minimum total wear (disk and rider) was obtained with iron-silicon bronze. As indicated in figure 3, the disk wear for this material was not detectable with a profilometer, even at a vertical magnification of 10 000.

Photomicrographs and surface profiles of the specimens are shown in figure 4. The lubricated specimens showed evidence of abrasion and plastic flow. The condition of the riders and disks indicated incipient surface failure from local surface welding (adhesion). Such conditions have been observed in previous boundary lubrication studies (ref. 14). Several earlier runs with iron-silicon bronze also showed this incipient failure. Also, higher friction coefficients (in the range of 0.13 to 0.18) were observed, but specimen wear was lower for this rider material than for the others. A slight change in surface speed or stress could have accounted for the wide variation in friction results for the iron-silicon bronze runs under borderline boundary lubrication conditions. The data reported in figure 3 are for stable boundary lubrication. It should be especially noted, however, that even when incipient failure and its accompanying higher friction levels were experienced, the wear rates for the iron-silicon bronze were lower than those for the other candidate materials.

When the fact that iron-silicon bronze performed best in these friction and wear experiments is considered, the initial Hertz surface stresses may be important. Calculations indicated that the initial Hertz stress for the iron-silicon bronze sliding on M-50 tool steel was 113 500 pounds per square inch and for M-50 sliding on M-50 was 149 000 pounds per square inch. The other material combinations with higher values of elastic modulus had nearly the same stress level as M-50 sliding on M-50. It has been found (ref. 15) that even for very small loads there is some plastic deformation of materials produced in such tests, whereas the Hertz formula assumes the materials are still in the elastic region. In general, because the stresses under consideration are at once triaxial and highly localized, their calculated values may often exceed the proportional limit and even the yield point of the material without causing damage.

The surface profiles in figure 4 show a buildup of material on the edges of the disk wear track. Disks from two sliding tests where incipient failure occurred are shown in figure 5 to indicate the formation of deposits along the wear tracks. This soft, black material was found to be an admixture of amorphous carbon, metal oxides, and loose wear debris that could be easily removed from the surface by rubbing. This material, which is also found in the used lubricant, will be discussed in the next section.

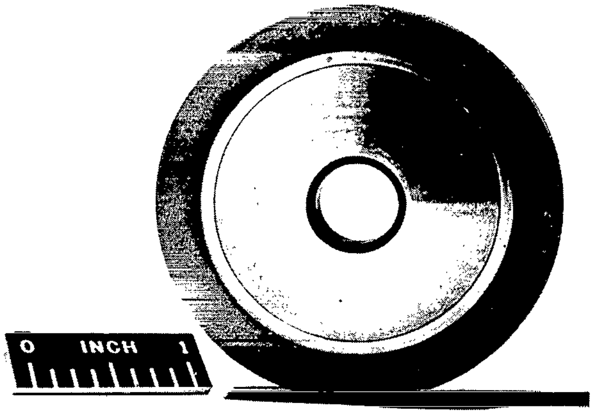
The importance of maintaining an adequate lubricating oil film was illustrated during a test with iron-silicon bronze when a failure occurred in the lubrication system at the start of one of the tests and the specimens were running almost dry. Figure 4(a) shows the condition of the specimens after a running time of only 15 seconds. Surface failure by welding was extensive, rider wear was high, and tearing out and metal transfer from the rider to the disk surface was appreciable. Similar loss of lubrication in a bearing probably would have resulted in catastrophic failure.

Introduction of the lubricant into a reduced-pressure atmosphere did not adversely affect the functioning of the drip-feed method of lubrication.

Effects on Properties of Lubricant

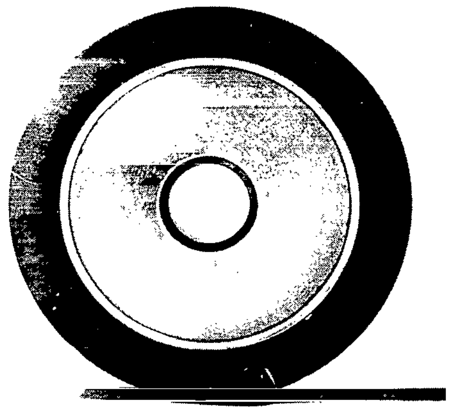
In addition to the friction and wear results, the accompanying effects on the polyphenyl ether lubricant during the sliding tests are also of major concern. Analysis of the oil before and after one of the most severe tests (M-50 rider sliding on M-50 disk) showed (1) little effect on the neutralization number, (2) a slight increase ($7\frac{1}{2}$ percent) in kinematic viscosity at 100° F, and (3) a negligible increase (3 percent) in kinematic viscosity at 210° F. Results of these analyses are given in table II.

The appearance of the lubricants after a typical sliding test with each rider-disk combination is shown in figure 6(a) as compared to the lubricant before use (fig. 6(b)). Figure 6 shows varying amounts of black, sludge-like



C-67835

(a) Disk run with Iron-silicon bronze rider.



C-67836

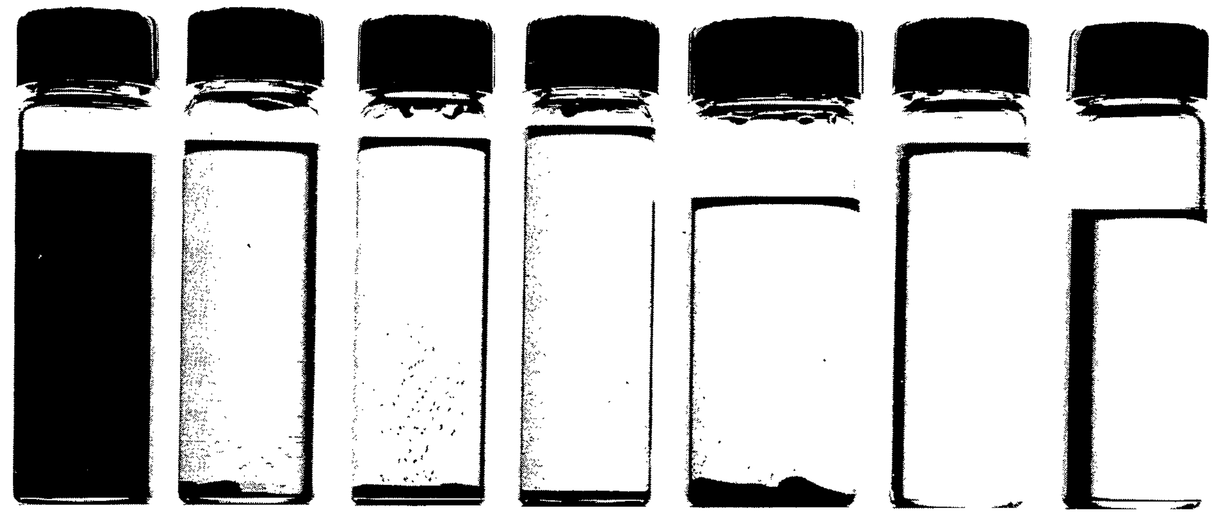
(b) Disk run with M-50 rider.

Figure 5. - Surface deposits obtained with various riders sliding on M-50 disks at ~300° F. Lubricant, polyphenyl ether; sliding velocity, 3600 feet per minute; load, 1000 grams; duration, 1 hour; ambient pressure, ~40 millimeters of mercury.

TABLE II. - EFFECT OF SLIDING FRICTION AND WEAR RUN ON PHYSICAL AND CHEMICAL PROPERTIES OF POLYPHENYL ETHER LUBRICANT

Lubricant (and designation)	Lubricant condition	Neutralization number, mg of potassium hydroxide/g		Kinematic viscosity, centistokes, at temperature of -				Change in viscosity during run, centistokes, at temperature of -		Lubricant appearance (see fig. 6)
		Value	Change during run	72.5° F	77° F	100° F	210° F	100° F	210° F	
Unsubstituted mixed-linked four-ring polyphenyl ether (ET-378, lot no. 12-2P)	New oil, as received	[a]0.27	-----	----	[a]177.5	[b]72.5	[b]6.5	---	---	Clear, amber
	Oil after sliding friction and wear run at 300° F for 1 hour with M-50 disk and M-50 rider	[c]0.17	-0.10	[c]233	-----	[d]78.0	[d]6.7	5.5	0.2	Turbid, slightly darkened amber

[a]Data from ref. 16.
[b]Extrapolated from data of ref. 16.
[c]Experimental data.
[d]Extrapolated experimental data.



(a) Lubricants after rider-material runs.

(b) Lubricant before run.

(c) Filtered lubricant after iron-silicon bronze run.

Figure 6. - Lubricant appearance before and after friction and wear experiments with five bearing-retainer materials sliding on M-50 disks at ~300° F. Lubricant, polyphenyl ether; lubricant flow rate at 250° F, 0.415 cubic centimeters per minute; sliding velocity, 3600 feet per minute; load, 1000 grams; duration, 1 hour; ambient pressure, ~40 millimeters of mercury.

sliding on the M-50 disk. The sludge was removed from the oil by centrifuging and drying. An analysis was made of the magnetic, very fine amorphous matter. About half of the material was a carbonaceous residue. This is probably the organic decomposition product resulting from the lubricant breaking down by highly localized frictional heating at the sliding contact points. The remainder of the material was iron, assumed to be iron oxide, which represents the disk and rider wear debris.

Results of Accelerated Thermal Stability Tests on Four- and Five-Ring Polyphenyl Ethers

When the SNAP-8 program was reoriented to include lubrication by organic fluids (specifically the polyphenyl ethers), there existed a possibility of lubricant degradation by thermal decomposition and/or catalytic action of mercury. The formation of solid decomposition products in a common leakage chamber could have a catastrophic influence on seal performance.

Results of accelerated thermal stability and mercury compatibility tests for both four- and five-ring polyphenyl ethers are given in table III. These results show no apparent reactivity between the fluids and no appreciable thermal breakdown of the oils. Earlier cursory compatibility studies in an open glass beaker with equal volumes of mercury and 5P4E polyphenyl ether showed no adverse effects when held at 170° C (338° F) for several hours. The fluids were immiscible; there were no apparent products of reaction; and the only noticeable effect was a slight darkening of the oil.

TABLE III. - EFFECT OF THERMAL BOMB STABILITY TESTS ON PHYSICAL AND CHEMICAL PROPERTIES OF

TWO POLYPHENYL ETHER LUBRICANTS (4P3E AND 5P4E)

Lubricant	Lubricant condition	Equivalent time at 300° F, hr	Neutralization number, mg of potassium hydroxide/g		Kinematic viscosity, centistokes, at temperature of -				Change in viscosity during run, centistokes, at temperature of -		Lubricant appearance
			Value	Change during run	72.5° F	77° F	100° F	210° F	100° F	210° F	
Unsubstituted mixed-linked four-ring polyphenyl ether (ET-378, lot no. 458-29-13)	New oil as received	0	[a]0.0	----	----	-----	[a]70.0	[a]6.25	---	----	Clear, light amber
	Oil after bomb stability run with mercury for 818 hours at 365° F	10 000	[b]0.02	0.02	[b]223	-----	[c]76.0	[c]6.6	6.0	0.35	Turbid, dark amber but no appreciable solid deposits
Unsubstituted mixed-linked five-ring polyphenyl ether (OS-124)	New oil as received	0	[b]0.02	----	----	[b]1394	[c]390	[c]13.8	---	----	Clear, colorless
	Oil after bomb stability run with mercury for 260 hours at 650° F	>10 000	[b]0.31	0.29	----	[b]3146	[c]800	[c]19.2	410	5.4	Turbid, dark brown but no appreciable solid deposits

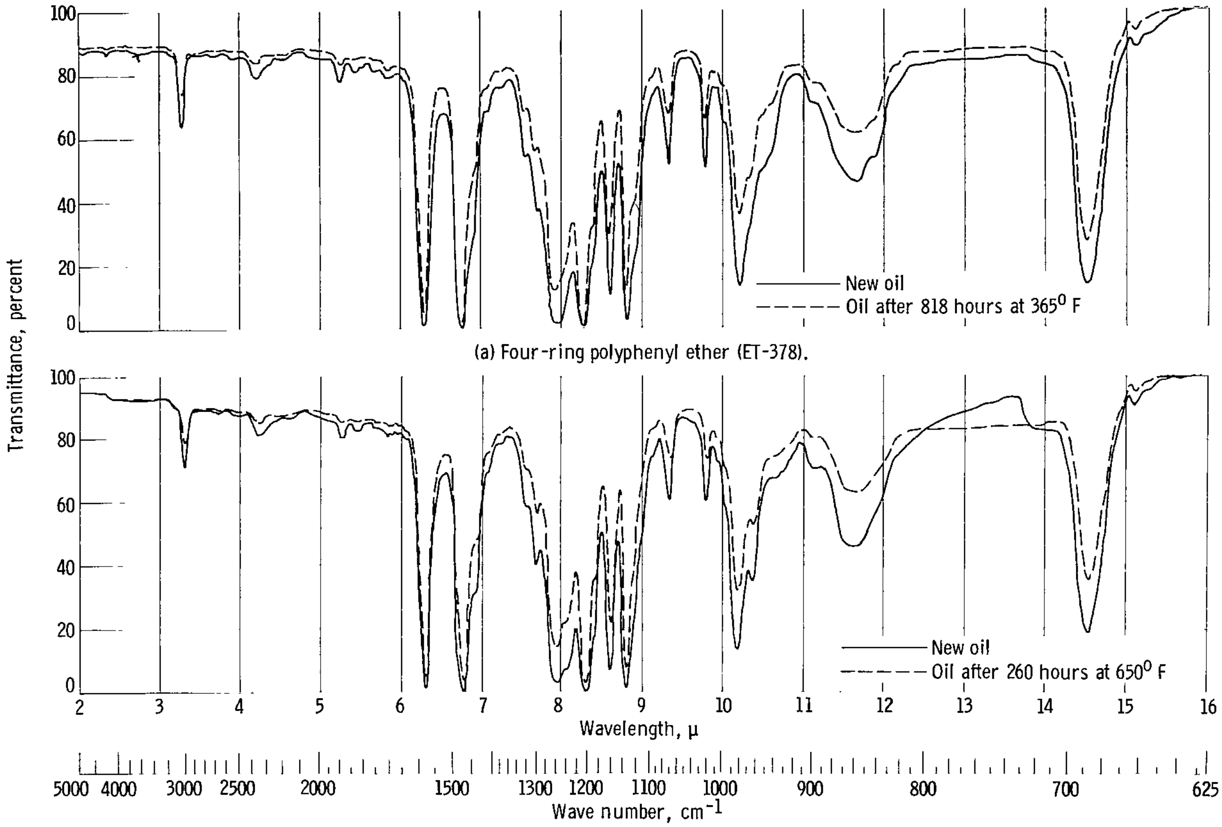
[a]Manufacturer's data.

[b]Experimental data.

[c]Extrapolated experimental data.

The high-temperature, low-pressure bomb compatibility studies were an attempt to simulate conditions even more severe than those expected for SNAP-8 operation (a 300° F oil temperature and a pressure equal to the vapor pressure of the oil at that temperature, with venting to a space environment for 10 000 hr). Based on the generalization that the reaction rate doubles for every 18° F temperature rise, the 818-hour 365° F test with the 4P3E oil shown in table III would be equivalent to operating for 10 000 hours at 300° F. The 260-hour 650° F test with the 5P4E oil was even more severe than the test with the 4P3E oil. A slight change in lubricant properties was noted for the 4P3E oil with a negligible neutralization number increase (0.02 mg of potassium hydroxide/g) and a kinematic viscosity increase of only 5.6 percent at 210° F. The 5P4E oil test showed reasonably small property changes, a neutralization number increase of 0.29 milligrams of potassium hydroxide per gram and a viscosity increase at 210° F of 39 percent.

Further evidence of the high thermal stability exhibited by the four- and five-ring polyphenyl ethers in the bomb reaction tests is shown in the infrared spectrophotometer analysis results of figure 7. Here infrared spectra were



(b) Five-ring polyphenyl ether (OS-124).

Figure 7. - Infrared spectrophotometer analyses of two mixed-linked polyphenyl ether liquids before and after bomb stability runs at elevated temperatures in contact with mercury.

made of diluted test lubricant samples before and after the bomb stability runs. The qualitative comparisons in the 2- to 16-micron-wavelength range showed the same general patterns for the new and used oils with no new peaks appearing. While these results indicate no major changes in the structure of the molecules, data at higher wavelengths might have shown different results. For example, the observed increase in viscosity may have resulted from polymerization.

SUMMARY OF RESULTS

From the experimental friction and wear investigation with polyphenyl ether fluid (mixed-linked four-ring Dow ET-378) acting as a boundary lubricant for five bearing-separator materials sliding on M-50 high-speed tool steel under simulated space power generation system conditions, the following results were obtained:

1. The most satisfactory material of those studied for use as bearing retainers lubricated with polyphenyl ether was an iron-silicon bronze alloy. The other retainer materials (S-Inconel, Stellite Star-J, M-2 and M-50 tool steel) always showed incipient surface failure and had less desirable friction charac-

teristics and total wear volumes greater than that of the iron-silicon bronze.

2. There was no gross breakdown of the lubricant during these 1-hour friction and wear experiments. Varying amounts of black deposits (primarily due to wear debris) formed on the outer edges of the disk specimens. Minor changes in lubricant appearance, as evidenced by a darker, turbid coloration, were due to mechanical as well as chemical phenomenon.

3. Extrapolated data from accelerated stability experiments (818 hr at 365° F) suggest that mixed-linked four-ring polyphenyl ether has adequate thermal stability for 10 000 hours at 300° F. Similar accelerated stability experiments (260 hr at 650° F) for five-ring polyphenyl ether also suggest adequate stability. Infrared spectroscopy results indicated no gross changes in molecular structure in the 2- to 16-micron-wavelength range. There were no new functional groups formed and no new bonds detected. The polyphenyl ethers were compatible with liquid mercury during the stability studies. There were no observed catalytic effects of the mercury on the decomposition of the oil.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 12, 1964.

REFERENCES

1. Schulman, Fred; Scott, W. C.; and Woodward, W. H.: Power Supplies. Space/Aeronautics Res. and Dev. Tech. Handbook 1964/1965, vol. 42, Sept. 1964, pp. 101-105.

2. Uzdarwin, R. J.: Literature Survey and Analytical Study of Polyphenyl Ethers - Determination of Performance Properties and Materials Compatibility for the SNAP-8 System. Rep. MR-63-061, Space-General Corp., Div. of Aerojet-General Corp., Apr. 1963.

3. Mahoney, C. L.; Barnum, E. R.; Saari, W. S.; Sax, K. J.; and Kerlin, W. W.: Nuclear Radiation Resistant High Temperature Lubricants. TR-59-173, WADC, Sept. 1959.

4. Klaus, E. Erwin; Fenske, Merrell R.; and Tewksbury, Elmer J.: Fluids, Lubricants, Fuels and Related Materials. TR-60-898, pt. II, WADD, Feb. 1962.

5. Mahoney, C. Lynn; Kerlin, William W.; Barnum, Emmett R.; Sax, Karl J.; Saari, W. S.; and Williams, P. H.: Engine Oil Development. TR-57-177, pt. II, WADC, Aug. 1958.

6. Ravner, H.; Russ, E. R.; and Timmons, C. O.: Anti-Oxidant Action of Metals and Organo-Metal Compounds in Fluoresters and Polyphenyl Ethers. NRL-5794, Naval Res. Lab., Dec. 1962.

7. Johnson, Robert L.; Swikert, Max A.; and Bisson, Edmond E.: Investigation of Wear and Friction Properties Under Sliding Conditions of Some Materials

7. Johnson, Robert L.; Swikert, Max A.; and Bisson, Edmond E.: Investigation of Wear and Friction Properties Under Sliding Conditions of Some Mate rials Suitable for Cages of Rolling-Contact Bearings. NACA Rep. 1062, 1952. (Supersedes NACA TN 2384.)

8. Anon.: Metals Handbook. Eighth ed., Vol. 1, ASM, 1961.

9. Anon.: Engineering Properties of Huntington Alloy Castings. Tech. Bull. T-41, Huntington Alloy Products Div., The Int. Nickel Co., Feb. 1962.

10. Anon.: Haynes Wear-Resistant Alloys Sales Manual. Haynes Stellite Co., July 1959.

11. Bhat, Gopal K.; and Nehrenberg, Alvin E.: A Study of Metallurgical Properties That Are Necessary for Satisfactory Bearing Performance and the Development of Improved Bearing Alloys for Service up to 1000° F. TR-57-343, WADC, Nov. 1957.

12. Macks, Fred.: Lubrication Reference Manual for Missile and Space Vehicle Propulsion at Temperature Above 700° F. TR-58-638, vol. 1, pt 1, WADC, Jan. 1959.

13. Bisson, Edmond E.; and Anderson, William J.: Advanced Bearing Technology. NASA SP-38, 1964.

14. Murray, S. F.; and Johnson, Robert L.: Effects of Chemically Active Additives on Boundary Lubrication of Steel by Silicones. NACA TN-3257, 1954.

15. Roark, Raymond J.: Formulas for Stress and Strain. Third ed., McGraw-Hill Book Co., Inc., 1954, p. 286.

16. Seplow, S.: Bis (M-Phenoxyphenol) Ether (ET-378) - Some Tests and Observations Relative to Its Degassing and Absorption Qualities of Selected Gases. TM 371:63-8-153, Aerojet-General Corp., 1963.

NASA-Langley, 1965 E-2507

2/22/85 JD

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.